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Effect of Western Spruce Budworm on Douglas-fir Cone Production in Western Montana

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RESEARCH SUMMARY

Douglas-fir cone production under various western spruce budworm defoliation conditions was examined in six stands west and six east of the Continental Divide in western Montana. The stands were stratified into two general defoliation levels: heavy, where defoliation and budworms were evident on over 50 percent of the trees; and light, where defoliation and budworms were not evident on the trees. Six dominant or codominant cone-producing trees were subjectively chosen at each site. Average cone production usually was higher in lightly defoliated stands. Comparison of cone production of individual trees and sites was not practical because of the large amount of variation in cone production observed between trees within stands and between stands within the infestation levels. Attempts to relate cone production to defoliation were not successful due to the variation in cone production and problems in accurately assessing past defoliation.

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INTRODUCTION

Western spruce budworm (*Choristoneura occidentalis* Freeman) larvae feed primarily on the current year's foliage of several host tree species including Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and western larch (*Larix occidentalis* Nutt.) (Johnson and Denton 1975). Budworm larvae also feed on developing and immature cones of Douglas-fir (Dewey 1970), western larch (Fellin and Shearer 1968), grand fir, subalpine fir, white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.), Engelmann spruce, and white spruce (*Picea glauca* [Moench] Voss) (Hedlin and others 1980).

The amount of seed disseminated into cutover areas or collected for artificial regeneration depends on both the number of cones produced and the extent of damage to cones and seed. A reliable estimate of the effect of budworm larvae on cone production, based on the level of defoliation, would help land managers decide whether to use natural or artificial means of reforestation.

The objective of this study was to examine the impact of western spruce budworm larval feeding on Douglas-fir cone production.

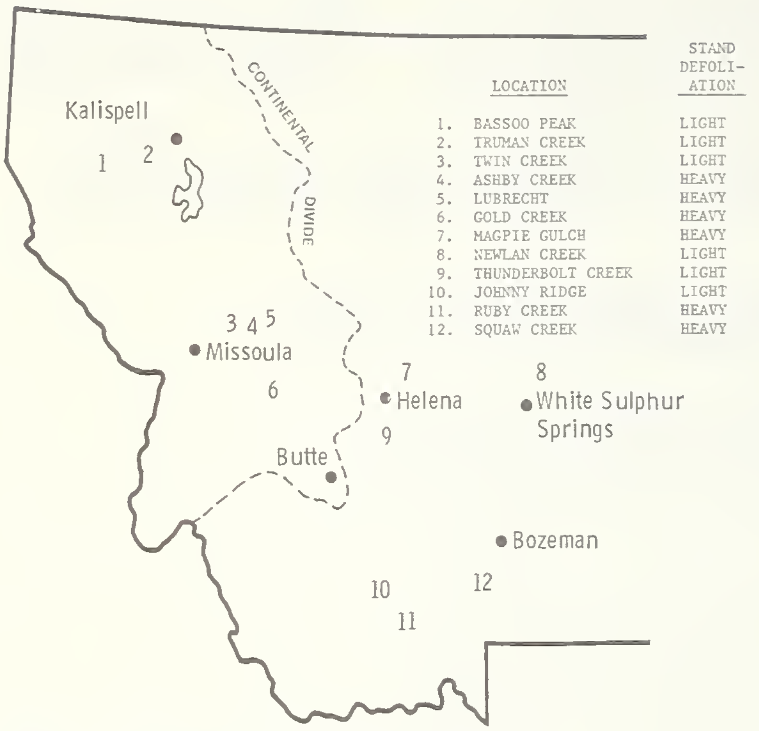
METHODS

Study sites were selected in 1978 and 1979 in western Montana within the *Pseudotsuga menziesii*/*Calamagrostis rubescens* habitat type (Pfister and others 1977) west of the Continental Divide, and from the more general Douglas-fir forest series east of the Continental Divide. The sites were stratified, based on ground observation, into two arbitrary defoliation classes: (1) heavy—budworm feeding on the foliage was evident on over 50 percent of the trees in the stand, and (2) light—budworm feeding on foliage was not evident. Three heavily defoliated and three lightly defoliated stands were selected both east and west of the Continental Divide (fig. 1).

Six dominant or codominant cone-producing Douglas-fir trees were subjectively chosen to sample at each site. Sampling was limited to 72 trees because of time constraints. Sample tree selection was restricted to trees whose tops were within the 53-ft (16-m) reach of a truck-mounted hydraulic bucket that was used to collect branch samples.

Ten sample branches from each tree were collected from a 10-ft (3-m) section in the crown of each tree beginning 5 ft (1.5 m) below the top—similar to the procedure used by Roe (1967). Dominant cone-producing branches were selected from all sides of the crown. On trees with fewer than 10 cone-producing branches, other dominant branches within the 10-ft (3-m) sample section were selected at random. Persistent cones, persistent peduncles (the stem attachment of the cone to the twig), and cone/peduncle scars were all tallied as "cones" for the cone crops occurring from 1974 (1973 growth) to 1979 (1978 growth). The cone/peduncle scars were differentiated from flower scars by the presence of a more prominent cone axis scar. The cones, peduncles, and scars were dated according to their internodal location on the branch. "Cones" were tallied by the year of occurrence for each of the 10 branches from each sample tree.

Average defoliation per sample tree was obtained by examining past internodes and expressed as "light" (0–37.5 percent), "moderate" (37.6–62.5 percent), or "heavy" (>62.5 percent) (Robinson and others 1978). Ratings were obtained for the entire tree from the 10 branches of each tree. The 1973 to 1979 internodes were rated (1974 cones occurred on 1973 foliage).



	LOCATION	STAND DEFOLI- ATION
1.	BASSOO PEAK	LIGHT
2.	TRUMAN CREEK	LIGHT
3.	TWIN CREEK	LIGHT
4.	ASHBY CREEK	HEAVY
5.	LUBRECHT	HEAVY
6.	GOLD CREEK	HEAVY
7.	MAGPIE GULCH	HEAVY
8.	NEWLAN CREEK	LIGHT
9.	THUNDERBOLT CREEK	LIGHT
10.	JOHNNY RIDGE	LIGHT
11.	RUBY CREEK	HEAVY
12.	SQUAW CREEK	HEAVY

Figure 1.—Location of study sites in western Montana.

RESULTS AND DISCUSSION

West of the Continental Divide, trees produced better cone crops in 1974, 1976, and 1978 than in 1975, 1977, and 1979 (fig. 2). Greater cone production occurred on trees growing within lightly defoliated stands compared to heavily defoliated stands in 1974, 1976, and 1978.

Cone production in stands east of the Continental Divide was usually lower and less uniform (fig. 3). Cones were produced in 1974 on all sites, but two of the highest cone-producing trees were located within heavily defoliated areas. Sample trees within the lightly defoliated stands produced again in 1977. In 1978, cones were produced at Thunderbolt Creek and Magpie Gulch. At Magpie Gulch, one of the six trees probably escaped serious budworm larval feeding on developing flowers and conelets and produced 86 of the 88 cones counted. In 1977 all of the lightly defoliated sites produced more cones than the heavily defoliated sites. In 1974 the heavily defoliated sites, as a whole, outproduced the lightly defoliated sites. These data support Boe's (1954) conclusion that good cone crops occurred at different times east and west of the Continental Divide. The time period covered by this study, however, was too short to adequately assess the comparative frequencies of good cone crops.

The Wilcoxon-Mann Whitney test (Wonnacott and Wonnacott 1972) substantiated the differences in cone production between infestation levels. Cone production in 1974, 1976, and 1978 west of the Continental Divide was significantly higher (99 percent confidence) in the lightly defoliated stands compared to heavily defoliated stands. East of the Continental Divide significantly more cones were produced in 1977 and 1978 in the lightly defoliated stands compared to the heavily defoliated stands. However, the reverse was true in 1974 when heavily defoliated sites outproduced lightly defoliated sites (90 percent confidence).

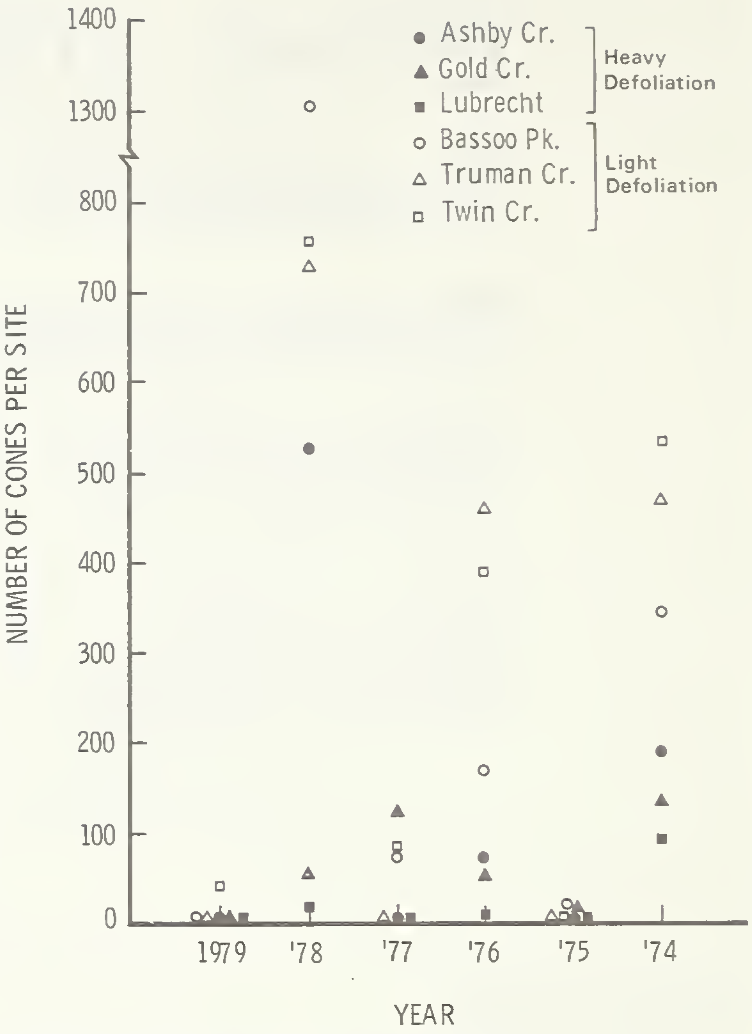


Figure 2.—Cone production west of the Continental Divide, estimated from 6 trees per site, 10 branches per tree.

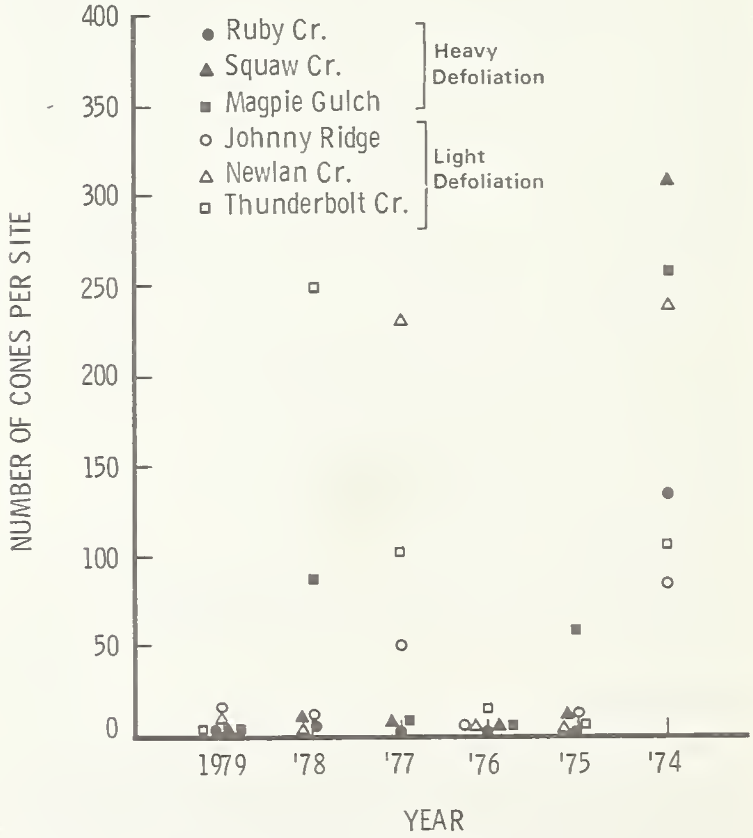


Figure 3.—Cone production east of the Continental Divide, estimated from 6 trees per site, 10 branches per tree.

There was considerable variation in mean cone production among trees on a given site (table 1).

Defoliation ratings for the trees west of the Continental Divide were averaged for 1976, 1977, and 1978 (table 2). These were the years most likely to affect 1978 cone crops based on principles established through research by Silen (1967), Owens (1969, 1973), and Allen and Owens (1972). For example, western spruce budworm feeding in 1978 included not only foliage but also developing conelets; defoliation in 1977 reduced the photosynthetic capacity of foliage needed for the 1978 reproductive bud development; and defoliation in 1976 provided unfavorable conditions for bud initiation, resulting in more vegetative buds or aborted buds. Pre-1976 defoliation estimates were generally high on all sites and included much natural needle mortality. Considerable variation in the levels of defoliation existed within and among trees (table 2).

At the lightly defoliated Bassoo Peak and Twin Creek sites, defoliation ranged from 20 to 45 percent on the sample trees. Some causal agent other than budworm probably was responsible for defoliation at Bassoo Peak in 1978 because no pupae cases or webbing was found and no defoliation occurred in 1977 or 1979. Early needle shed of 1977 foliage was observed in the fall of 1979 at the Twin Creek site. This sloughing appeared not to be budworm related and indicated that the 1976 defoliation may be overestimated. For Bassoo Peak, defoliation values were recalculated based on the 1976 and 1977 foliage ratings, and for Twin Creek, values were recalculated based on the 1976 and 1978 foliage ratings. The values were then compared to mean defoliation of the other stands. After these adjustments were made, the defoliation estimates for lightly defoliated stands west of the Continental Divide were closely grouped between 10 and 20 percent. However, since causes of the defoliation could not be identified we felt it best to use the original observation (fig. 4).

Mean defoliation values were also calculated for the stands east of the Continental Divide (table 3). Because 1977 was the most recent year in which cone production occurred in most of the stands, defoliation was averaged for 1976 and 1977. Cone production east of the Continental Divide was not directly related to mean defoliation as measured in this study (fig. 5).

Table 1.—Mean cone production for 6 trees (10 branch samples per tree) at each study location west and east of the Continental Divide by heavy or light defoliation, 1976–78

Defoliation and location	1978			1977			1976		
	Total cones/ site	Mean cones/ tree	S.D.	Total cones/ site	Mean cones/ tree	S.D.	Total cones/ site	Mean cones/ tree	S.D.
West of Continental Divide									
HEAVY									
Ashby Creek	532	88.6	70.1	74	12.3	23.0	193	32.2	21.9
Gold Creek	53	8.8	8.0	51	8.5	6.2	137	22.8	9.8
Lubrecht	16	2.7	6.0	2	0.3	0.8	97	16.2	9.2
LIGHT									
Bassoo Peak	1,312	218.7	70.3	170	28.3	29.4	352	58.7	50.8
Truman Creek	741	123.0	44.9	464	77.3	120.0	479	79.8	41.2
Twin Creek	765	127.5	55.8	396	66.0	56.4	546	91.0	51.4
East of Continental Divide									
HEAVY									
Ruby Creek	4	0.7	1.6	0	0.0	0.0	135	22.5	32.7
Squaw Creek	7	1.2	4.4	7	1.2	4.4	312	52.0	38.6
Magpie Gulch	88	14.7	35.0	7	1.2	1.6	262	43.7	23.9
LIGHT									
Johnny Ridge	8	1.3	2.8	49	8.2	17.7	84	14.0	10.1
Newlan Creek	2	0.3	0.8	234	39.0	32.9	243	40.5	35.5
Thunderbolt Creek	252	42.0	24.3	104	17.3	33.8	107	17.8	9.0

Table 2.—Mean defoliation for sample trees west of the Continental Divide, 1976 - 1978

Defoliation and location	Tree	Mean	S.D.
		Percent	
HEAVY			
Ashby Creek	1	68.3	22.4
	2	59.6	29.7
	3	81.3	17.0
	4	72.1	27.4
	5	54.6	36.7
	6	80.0	24.7
Gold Creek	20	54.2	35.3
	21	55.8	27.8
	22	55.0	27.2
	23	45.0	27.2
	24	84.6	9.1
	25	82.5	13.4
Lubrecht	68	65.4	36.1
	69	69.5	32.6
	70	85.8	30.0
	71	82.5	8.6
	72	95.8	37.1
	73	65.4	12.5
LIGHT			
Bassoo Peak	7	37.9	38.6
	8	43.8	41.2
	9	40.0	45.4
	10	42.9	39.8
	11	28.3	27.3
	12	30.4	35.5
Truman Creek	13	9.6	11.7
	14	12.1	10.6
	16	15.0	12.9
	17	14.6	17.7
	18	9.2	16.1
	19	12.1	15.9
Twin Creek	62	23.7	16.2
	63	15.4	16.3
	64	19.6	17.9
	65	31.2	22.0
	66	20.4	18.7
	67	15.4	18.5

Table 3.—Mean defoliation for sample trees east of the Continental Divide, 1976-1978

Defoliation and location	Tree	Mean	S.D.
		Percent	
HEAVY			
Magpie Gulch	50	37.5	30.3
	51	42.5	23.8
	52	60.0	26.5
	53	71.3	21.9
	54	97.5	5.1
	55	75.6	27.0
Ruby Creek	26	53.8	28.4
	27	78.1	19.4
	28	42.5	28.8
	29	48.8	23.6
	30	45.0	28.2
	31	47.5	31.8
Squaw Creek	38	73.1	23.7
	39	48.8	31.9
	40	88.1	10.3
	41	51.9	32.8
	42	33.8	26.0
	43	60.6	28.8
LIGHT			
Newlan Creek	44	32.5	23.8
	45	51.3	27.5
	46	20.0	11.8
	47	41.3	27.2
	48	24.4	17.9
	49	45.0	25.8
Johnny Ridge	32	43.1	28.5
	33	33.3	30.4
	34	32.5	24.8
	35	23.8	25.3
	36	35.0	29.0
	37	48.1	27.3
Thunderbolt Creek	56	48.1	32.8
	57	51.3	32.7
	58	39.4	29.9
	59	62.5	30.1
	60	23.8	25.0
	61	27.5	18.8

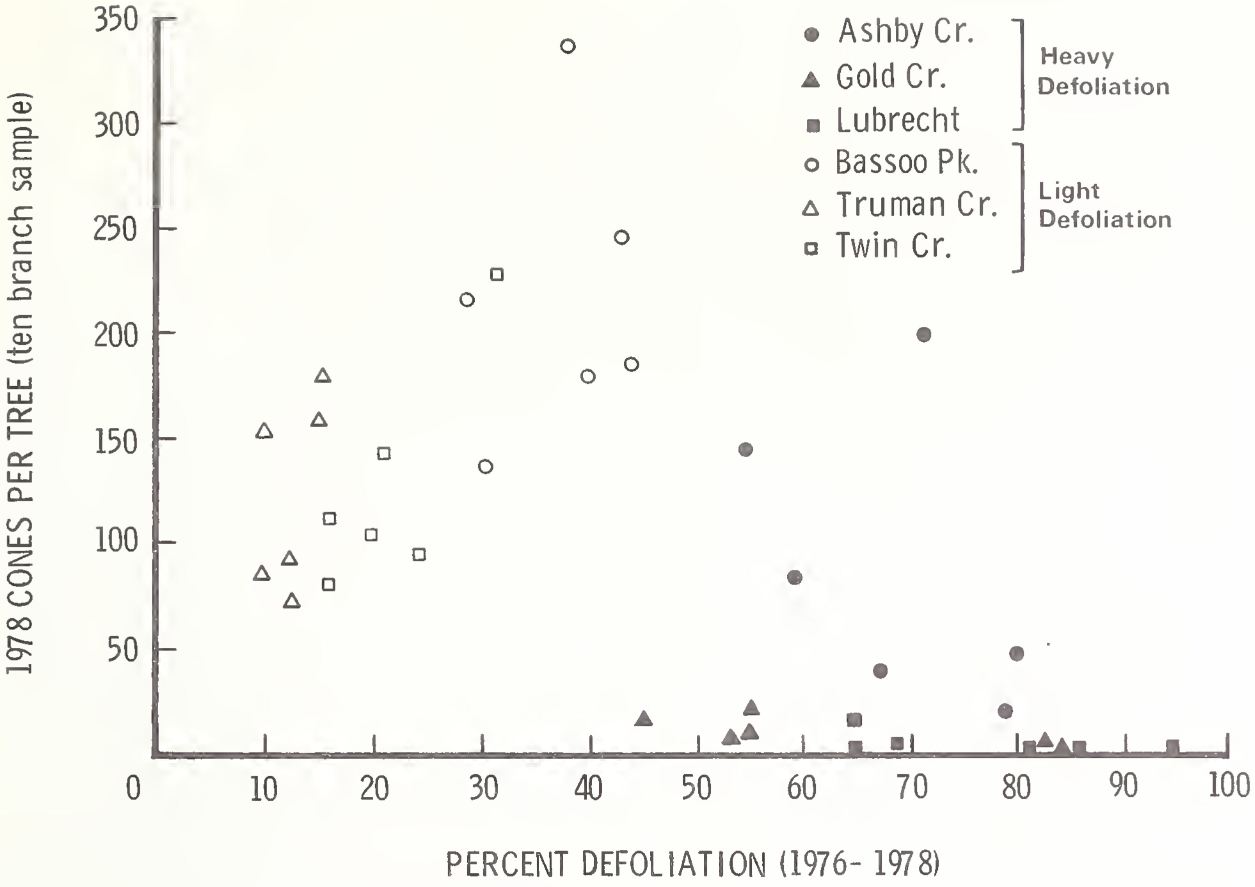


Figure 4.—Cone production and average defoliation west of the Continental Divide.

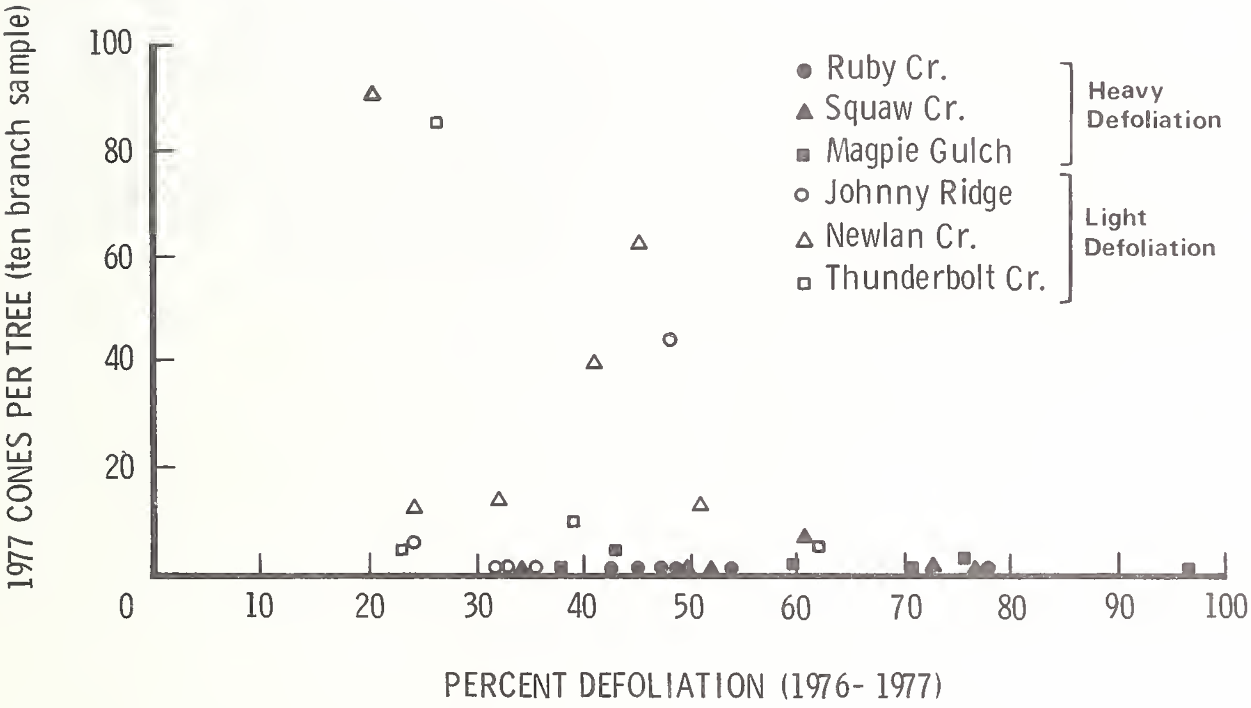


Figure 5.—Cone production and average defoliation east of the Continental Divide.

These results indicate that western spruce budworm can decrease Douglas-fir cone crops through the combined effects of direct feeding on reproductive buds and general defoliation. The magnitude of these losses is not known. If normal production for 10 branches for 6 trees/site west of the Continental Divide was 750 cones in 1978 as it was at Twin Creek and Truman Creek, losses in relatively young and vigorous stands with moderate to heavy defoliation similar to Ashby Creek would approximate 30 percent. Losses in heavily defoliated and less vigorous stands such as Gold Creek and Lubrecht could approach 90 to 95 percent; however, due to the large amount of variation between trees and sites, these must be considered only as rough estimates.

It was impossible to distinguish between the losses due to failure of reproductive bud differentiation caused by stress from defoliation and the losses due to budworm feeding during the early stages of bud burst and flower development. An attempt was made to count not only persistent cones, peduncles, and cone scars, but also to tally latent buds and dead reproductive buds and flowers for a comparison of the number of reproductive structures initiated; this is similar to the procedure used by Schooley (1978). This method did not work because the dead flowers were not persistent and latent buds were too numerous and small to be recorded with accuracy. In normal stand conditions, the separation between losses to defoliation stress and losses to feeding may not be important. But if seed were needed, individual trees could be sprayed to prevent budworm damage to flowers and cones.

In determining average defoliation for each year, 10 defoliation samples from each tree were inadequate; 20 samples did not improve the estimated mean, standard deviation, or coefficient of variation. The present method using rating codes applies discrete values to a continuous variable. This is confounded by the haphazard feeding patterns of the budworm. Not only does the intensity of defoliation change throughout the crown, defoliation is not necessarily consistent within a branch. Consequently, relatively large standard deviations were associated with low to moderate mean defoliation levels (< 60 percent) for the trees west of the Continental Divide. Heavy defoliation levels (> 60 percent) resulting from more uniform and severe attacks generally had smaller associated standard deviations and lower coefficients of variation (< 40 percent), indicating a better estimate. Some other descriptor may be more appropriate and in fact essential for reliability in low to moderate defoliation conditions.

The importance of the duration of defoliation is suggested in the differences in cone production between the more recently defoliated Ashby Creek site and the historically defoliated Lubrecht and Gold Creek sites. To study the effects of the duration of defoliation on cone production, a more complete tree-to-tree history is necessary.

The large amount of variation in cone production at all levels of the sampling hierarchy—between branches within trees, between trees within sites, between sites within infestation levels, and between infestation levels within a general geographic region—rendered traditional sampling systems almost useless. This, coupled with the other factors that control cone production—such as weather (Lowry 1966; vanVredenburch and LaBastide 1969; Eis 1973), genetic difference (Eis and others 1965; Griffith 1968), carbohydrate levels (Kramer and Kozlowski 1960; Eis and others 1965; Kozlowski 1971; Ebell 1971), and levels of growth hormones (Ross and Pharis 1976; Pharis and Kuo 1977)—prevented any reliable means of isolating the budworm's impact on cone production.

Based on these results, if accuracy to within ± 10 percent of the true mean with 95 percent confidence is required for estimates of cone production, 100 percent sampling of the cone branches per tree would have been necessary. Sampling of this intensity is unrealistic in most studies. Consequently, the researcher should be ready to accept the large amounts of inherent variation or develop a more effective sampling method.

The results from this study show that western spruce budworm infestations caused lower Douglas-fir cone production in several stands west of the Continental Divide in Montana. Results from further cone production studies will be enhanced by understanding: (1) the factors affecting cone production such that budworm damage within and between trees can be isolated for site comparisons; (2) the effect of defoliation (both amount and duration) on cone production, including a more accurate description or estimator of defoliation; and (3) the decrease in cone production due to direct larval feeding or to defoliation stress.

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Douglas-fir cone production in stands of heavy or light western spruce budworm defoliation conditions was examined at 12 western Montana study sites on 72 trees. Average cone production was usually higher on sites where budworm defoliation was light compared to heavily defoliated stands. Attempts to analyze cone production of individual trees and sites were unsuccessful because of the large amount of variation in cone production between trees within sites and between sites within the infestation levels.

KEYWORDS: cone production, defoliation, Douglas-fir, *Pseudotsuga menziesii* var. *glauca*, western spruce budworm, *Choristoneura occidentalis*

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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